RESEARCH ARTICLE
doi: 10.2306/scienceasia1513-1874.2006.32.53

AGNPS Model Assessment for a Mixed Forested Watershed in Thailand

Mohamed Mujithaba Mohamed Najim,[a*] Mukand Singh Babel[b] and Rainer Loof[b]

[a] Department of Agricultural Engineering, Faculty of Agriculture, University of Peradeniya, Peradeniya, Sri Lanka.
[b] Water Engineering and Management Program, School of Civil Engineering, Asian Institute of Technology, Klong Luang, Pathumthani 12120, Thailand.

* Corresponding author, E-mail: mnajim@pdn.ac.lk

Received 26 Apr 2005
Accepted 17 Aug 2005

ABSTRACT: Watershed modeling, as a tool to identify environmental problems, is becoming more popular. The modeling approach will allow evaluating present scenarios and possible remedial measures and strategies. The present study attempts to verify the suitability of the Agricultural Non-Point Source (AGNPS) pollution model developed for an agricultural watershed, for a mixed forested watershed. The study watershed, Huai Nong Prong in Southeastern Thailand, is a mixed forested watershed with 26% forest, 25% mangrove forests, and 36% agro-forests. Extensive fieldwork was completed to collect data and information needed for the model preparation and application. The study revealed that the AGNPS model produces satisfactory results regarding runoff volume and soluble nitrogen yields for the watershed. The sediment yield prediction is marginal for the selected watershed, partially attributed to the mangroves and the pools in the streams, which act as sediment traps. This suggests that mangroves in the downstream end of the watershed could act as natural wetlands capable of neutralizing or reducing environmental problems created by a watershed. The model, however, could not accurately simulate the peak flows, suggesting the peak flow simulating approach in AGNPS does not suitably predict peak flows from mixed forested watersheds.

KEYWORDS: Non-point source pollution, calibration, flow modeling, forest, nutrients, runoff.

INTRODUCTION

Conversion of forests for agricultural activities has increased in many Southeast Asian countries. In past few decades, deforestation in Thailand has been very rapid and the forestland has been converted into agricultural land, which has created many environmental problems such as erosion, sedimentation, and eutrophication. Also, the increased use of agro-chemicals has deteriorated the quality of water generated from encroached watersheds.

Soil erosion in southeastern Thailand is recorded as severe, with 62.2% of the forested area encroached upon by agricultural activities during last 30 years. These lands are mainly cultivated with crops such as cassava and sugarcane, which accelerate soil erosion and depletion of soil fertility. The predicted soil loss in the area is 34 t/ha/year. The loss of soil has caused nutrient losses, consisting mainly of nitrogen, phosphorous and potassium. This has decreased cassava yields from 30 t/ha to 16 t/ha during the past 30 years[1].

The southeastern coast of Thailand is an area with aquaculture activities. The mangrove forests, which are an important ecosystem, are facing the threat of destruction because of their conversion to aquaculture. Because of this threat, the Kung Krabaen Bay Royal Development Project (KKBRDP) has initiated the conservation of the mangroves, educating and encouraging farmers to replant them in selected areas.

In the United States, Canada and Europe, water and land quality issues have been analyzed and evaluated with the aid of computer models. Scientists have put forward substantial efforts in the last two decades towards developing watershed scale non-point source pollution models. As a result, several computer models have been developed for predicting erosion, sediment transport and nutrient and chemical transport from watersheds mainly having agricultural activity. These models are effective and very useful tools in watershed planning, development and management and can play a significant role in evaluating possible remedial measures and strategies for soil, water and nutrient conservation to improve watershed quality.

The AGricultural Non-Point Source (AGNPS) pollution model is an event based, distributed parameter computer simulation model, which subdivides the watershed into uniform cells. Each cell homogenously represents the environmental factors. AGNPS routes runoff, sediment and chemical transport through cells in a stepwise manner, proceeding from the headwaters to the outlet. Basic model components of AGNPS are hydrology, erosion and sediment and chemical transport.

The hydrology component estimates runoff volume and peak flow. Runoff is estimated using the Soil Conservation Service (SCS) curve number method, while peak flow is estimated with an empirical relationship used in the Chemicals, Runoff and Erosion from Agricultural Management System model (CREAMS)[2]. Wirojanagud et al.[3] applied curve number method to determine the runoff generated from portions of non-irrigated areas in a 143 km^2 watershed in Khon Kaen, Thailand. Hydrographs generated from the watershed agreed well with the observed data, with the exception of that from the early crop growth period.

Soil loss and sediment yield are simulated as a two-step process. A modified form of the Universal Soil Loss Equation (USLE) is used to define soil loss for each cell for a single storm event[2,4]. Sediment is routed from cell to cell through the watershed to the outlet using a sediment transport and depositional relationship, which is based on a steady-state continuity equation[2]. Watanasak[5] developed the erosion maps of Chonburi and Rayong provinces using soil maps, Landsat imagery techniques, nomograph[6] and USLE. Funnpheng et al.[7] applied USLE and Geographical Information Systems (GIS) software to a watershed in Phetchabun province, Thailand, and developed a potential soil erosion map. They used a soil erodibility factor (K), slope and gradient index (LS), rainfall erosivity index (R) and crop factor (C) to develop the map.

The chemical transport component of the model estimates nitrogen, phosphorous and chemical oxygen demand (COD) throughout the watershed. Soluble pollutants and sediment-attached pollutants are calculated separately from a profile of available nutrient concentrations in the top 1 cm of soil[2,4].

AGNPS has been developed and used for objectively evaluating non-point source pollution from agricultural watersheds and abatement strategies. Bingner et al.[8] used several non-point source models, including AGNPS, to simulate runoff and sediment yields from three small watersheds in Mississippi and found AGNPS to provide better results compared to other models. Macalpine et al.[9] used AGNPS for the Pine Lake Watershed in Canada, and they found that prediction of phosphorous concentrations by AGNPS were 10 to 100 times higher than those observed. Fisher et al.[10] analyzed AGNPS in terms of spatial sensitivity of soil properties and land use categories on the model output and concluded that chemical discharge outputs from AGNPS have little or no sensitivity to the spatial distribution of these input data. Mostaghimi et al.[4] concluded from their study that the runoff, sediment yield, nitrogen and phosphorous loading predicted by AGNPS model compared favorably with observed values. Perrone and Madramootoo[11] used AGNPS to evaluate the effectiveness of best management practices (BMP) on water quality improvements.

Most previous work with the AGNPS model was applied to relatively flat or moderately sloped predominantly agricultural watersheds. The AGNPS model applicability and suitability in tropical environments with mixed forests needs to be assessed in order to use it as a tool in assessing forested watersheds. Watershed modeling in developing countries is relatively new and not much modeling efforts have been done. Therefore, the predictive power of watershed models is not made use in watershed management. In this study, the AGNPS model was applied in order to verify the applicability of the model for the simulation of runoff, sediment and nutrient yields from a mixed forested watershed in Thailand.

MODELING APPROACH

Simulation Model

The AGNPS is an event based, distributed parameter computer simulation model developed by the Agricultural Research Service (ARS) in cooperation with the Minnesota Pollution Control Agency and the Soil Conservation Service[2]. The model subdivides the watershed into uniform grids called “cells”. Potential pollutants are routed through cells in a stepwise manner, proceeding from the headwaters of the watershed to the outlet. The model can be used to predict runoff volume and peak flow, as well as sediment, nutrient, and pesticide yields for single storm events at any point in a given watershed. The nutrients considered include nitrogen and phosphorous, both essential plant nutrients and major contributors to surface water pollution. In addition, the model considers point sources of water, sediment, nutrients, and chemical oxygen demand (COD) from animal feedlots and springs[2].

Model components use equations and methodologies that are well established and extensively used by agencies such as the USDA Soil Conservation Service (SCS). Further details on the theoretical background of AGNPS can be found in Young et al.[12].

Data Collection And Analysis

The study watershed, Huai Nong Prong (Lat 12°33¢-12°36¢ N and Long 101°53¢-101°55¢ E) with an area of 2.85 km^2, shown in Figure 1, is located in the southeastern region of Thailand. A part of the watershed is located within the Kung Krabaen Bay Royal

Development Project area. The average temperature of the area is 26.8°C, and it is rather uniform throughout the year. The area has an average annual rainfall of 2874 mm, 90% of which falls during May to October leaving only 10% for the remaining six dry months.

Since 1998, the Land Development Department of the government of Thailand (LDD) has been collecting rainfall, runoff, sediment and nutrient data from the study watershed. The rainfall is measured by a siphon type-recording rain gauge. A calibrated "V notch" weir is installed at the outlet of the watershed to measure the flow using a water stage recorder. The water level recorder installed at the outlet of the watershed records the water levels over time. These charts were converted to runoff hydrographs using the calibration curve developed by the LDD. Water samples are collected at the watershed outlet and brought to the LDD laboratory for analysis of total nitrogen, total phosphorous and sediment.

An extensive field investigation was conducted to determine land uses, channel network, channel types and their dimensions, and the conservation measures being practiced within the agricultural lands of the watershed areas, with the help of aerial photographs of 1992. Analysis of field data as shown in Table 1, reveals that the watershed is covered with, 26% forest, 25% mangrove forests, 5% rangeland and 1% grasslands. Of the agricultural lands, 36% are densely grown rubber and orchards with a dense under cover, which could be considered as agro-forests. Only 5% of the area is used for intensive cultivation of cassava. Therefore, the mixed forested area in the watershed is 93%, including densely grown rubber and orchards with well grown under cover.

The semi-detailed soil map developed by Rimchala et al.[13] for the study area was used in identifying and sampling the major soil types and to measure the field slope. The average slope of each land use is also given in Table 1. Several soil samples (3 to 5) were collected and bulked from each soil group identified by Rimchala et al.[13]. A representative soil sample was taken from each bulked soil sample and analyzed for particle size distribution by the hydrometer method[14], total nitrogen by the micro Kjeldahl method[15], total phosphorous by the perchloric acid digestion method[15] and organic matter contents by dichromate oxidation method[15]. A representative rainwater sample from a bulk sample of 5 rainfall events was analyzed for nitrogen concentration by the micro Kjeldahl method[16].

The kinetic energy of rainstorms (EI) was calculated from daily recording rain charts by subdividing the rain into specific intensity ranges[17]. The water stage records were converted to discharge data using the rating curve developed by the LDD. As the streams in the watershed are ephemeral and intermittent streams, the straight-line method[18] was used in the base flow separation in order to produce the direct runoff hydrograph. The runoff volume generated by each rainfall events was calculated using the direct runoff hydrograph. Details of calculations and results of EI and runoff are given in Najim[19].

The soil erodibility factor (K) for each soil type in the watershed was found from a nomograph[6] using measured soil textural parameters and organic matter contents. The SCS Curve Number (CN)[12,20,21], crop management factor (C)[12,22], supporting practice factor (P)[20], surface condition constant[12], chemical oxygen demand (COD) factor[12], and Manning's roughness

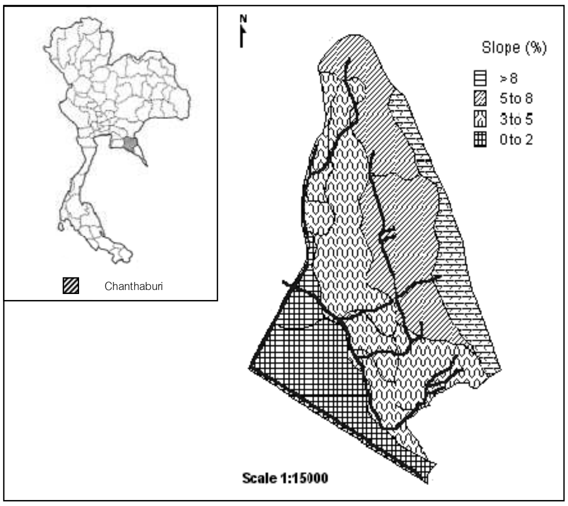

Fig 1. Study watershed Huai Nong Prong.

Table 1. Land use types in the Huai Nong Prong watershed.

Land Use Type	Area (ha)	Area (%)	Average Slope (%)
Forest	144.69	50.77	
Natural forest	67.97	23.85	19.8
Planted forest	6.09	2.14	19.8
Mangrove forest	70.63	24.78	3.3
Agro-Forests	116.72	40.96	
Rubber	76.72	26.92	6.0
Orchard	24.84	8.72	3.3
Intensive Agriculture	15.16	5.32	
Cassava	15.16	5.32	7.3
Other	23.60	8.29	
Grass	3.75	1.32	6.0
Bare land	2.50	0.88	9.9
Aquaculture	1.88	0.66	0.0
Rangeland	15.47	5.43	7.3
Total	**285.00**	**285.00**	**100.00**

coefficient for overland and channeled flows[12] were taken from the literature, and are given in Najim[19]. Curve Numbers were converted to fit for the wet and dry moisture conditions using the AGNPS users' guide[12].

Model Application and Evaluation

A uniform grid system, with cells of 2.5 ha, was superimposed on the watershed, which generated 114 base cells. However, to better represent the variation in model parameters, such as the land use, soil and slope differences, some of these cells were divided into smaller areas, which resulted in a total of 309 cells with 70 base cells, 155 sub-cells, each representing one quarter of a cell, and 84 sub-sub-cells, each representing one sixteenth of the base cell.

The measured nitrogen concentration of the rainfall was 0.77 ppm. Observed rainfall depth and the corresponding calculated EI values were entered in the model (Table 2). Flow directions identified from areal photographs and field visits were assigned to the cells. CNs were assigned to each cell according to land use and the initial SCS antecedent moisture condition (AMC) for each event. A weighted average value of the C factor, surface condition constant, and COD factor was calculated if there were variations in land use within a particular cell. The P factor was assigned based on the conservation measures adopted. Fertilizer application and timing were considered in the simulation. The channel type for each cell was assigned accordingly. The downstream end of the main stream passes through the mangrove forest and contains big pools. Wherever, the pools were available, the data related to the channel were entered accordingly.

The model was calibrated using 4 rainfall events from 1998 and validated using 6 rainfall events from 1999. A total of 10 rainfall events were simulated. Table 2 lists the rainfall events, amounts, duration and the calculated EI values. The surface runoff component of the model was calibrated by varying the CN parameter independently for each land use type in each cell or sub cell. The curve numbers obtained from initial SCS antecedent moisture conditions were proportionately adjusted for each cell or sub cell. The sediment yield estimation was improved by proportionately varying the cropping factor (C) in the USLE and the hydrographic shape factor[11]. The hydrograph shape factor, which gave the best fit to the watershed considered, was found by varying it in the initial data screen and simulating for different events. The best-fit hydrograph shape factor was used for all other simulations including the calibration of sediment yield. The nutrient yields generated by the watersheds were calibrated by defining a user assigned factor representing the decay of the nutrients within the cells. During the calibration process, each change was done in all the cells or sub cells having same type of inputs.

The model performance was evaluated by calculating the coefficient of performance (CP'_A) and the percent error between observed and simulated parameters. The CP'_A is give by James and Burgess[23] as follows:

$$CP'_A = \frac{\sum_{i=1}^{N}\left[S(i)-O(i)\right]^2}{\sum_{i=1}^{N}\left[O(i)-O_{avg}\right]^2}$$

where $O(i)$ is the ith observed parameter value, O_{avg} is the mean of the observed parameter values, $S(i)$ is the ith simulated parameter value, and N is the total number of events. The coefficient of performance approaches zero as the observed and simulated values get closer. The CP'_A will be zero for a perfect match.

Results

Model Calibration and Validation

The CP'_A for runoff calibration was about 2 when the initial CNs were the inputs to cells. During the calibration process, the CN was reduced until, at 9% reduction, the CP'_A for runoff calibration was 0.09 and further reduction of the CN increased CP'_A. In the same

Table 2. Rainfall events simulated for AGNPS model calibration and validation.

Process	Event	Date	Rainfall, mm	Duration of Rain, h	EI, $Jm^{-2}mm^{-1}h^{-1}$
Calibration	1	11/Sep/1998	44.8	9.0	7.38
	2	16/Sep/1998	56.6	3.0	5.73
	3	17/Sep/1998	43.5	3.0	2.08
	4	13/Oct/1998	35.2	1.0	2.17
Validation	5	16/Jun/1999	38.4	4.0	1.37
	6	17/Jun/1999	43.5	4.5	4.78
	7	18/Jun/1999	33.9	4.5	4.15
	8	05/Jul/1999	42.5	2.0	1.40
	9	14/Oct/1999	32.2	3.5	4.29
	10	29/Oct/1999	38.4	2.0	2.89

Table 3. AGNPS model calibration and validation results for the hydrology component.

	Rainfall		Runoff volume (m^3)			Peak flow (m^3/s)		
	Event	Depth, mm	Obs.	Sim.	% Error	Obs.	Sim.	Ratio
Calibration								
	1	44.8	27125	21564	20.5	0.695	4.298	6.18
	2	56.6	37092	38097	-2.7	1.296	7.186	5.54
	3	43.5	18759	20126	-7.3	0.615	4.020	6.54
	4	35.2	6881	3594	47.8	0.278	0.792	2.85
				CP'_A = 0.09			Average	5.28
Validation								
	5	38.4	11432	14478.0	-26.7	0.405	2.976	7.34
	6	43.5	16549	20269.2	-22.5	0.814	4.022	4.94
	7	33.9	8495	10134.6	-19.3	0.858	2.140	2.49
	8	42.5	17692	19545.3	-10.5	0.890	3.804	4.27
	9	32.2	7123	8686.8	-21.9	0.245	1.888	7.71
	10	38.4	12899	14478.0	-12.3	0.543	2.976	5.48
				CP'_A = 0.38			Average	5.37
Both Calibration and Validation								
				CP'_A = 0.09			Average	5.33

Obs. = Observed; Sim. = Simulated.

way, the C factor was reduced during sediment calibration. The CP'_A for sediment calibration decreased to 0.44 when the reduction was 20%. Nitrogen and phosphorous calibration gave best results when allowed decay was 8% and 13%, respectively.

The calibration results for the hydrology component are presented in Table 3. The simulated runoff volume reasonably matched with the observed runoff volume, with a coefficient of performance (CP'_A) of 0.09. The peak flow generated by the model is between 5 to 6 times the observed peak discharge, except in event 4 (Table 3).

The model validation results in Table 3 indicate that the model can reasonably simulate surface runoff volume with less than 25% error in the prediction. The runoff volumes generated by the validation process results in an average CP'_A of 0.38, which is larger than the CP'_A (0.09) for the calibration process (Table 3). When all the events used for the calibration and validation are considered, the average CP'_A for the runoff volume is 0.09, which is satisfactory. Again, the peak flow is over-predicted by an average of 537% (Table 3), similar to the results obtained in the calibration process (Table 3).

Table 4. AGNPS model calibration and validation results for the sediment and nutrients.

	Rainfall (mm)		Sediment (t)			Soluble Nitrogen (ppm)			Soluble Phosphorous (ppm)		
	Event	Depth	Obs.	Sim.	% Error	Obs.,	Sim.	% Error	Obs.	Sim.	% Error
Calibration											
	1	44.8	2.032	1.343	33.9	0.20	0.36	-80.0	0.01	0.01	0.0
	2	56.6	1.254	1.551	-23.7	0.26	0.34	-30.7	0.01	0.01	0.0
	3	43.5	0.494	1.043	-111.1	0.26	0.36	-38.5	0.01	0.01	0.0
	4	35.2	0.137	0.426	-210.9	0.75	0.51	32.0	0.01	0.01	0.0
				CP'_A = 0.44			CP'_A = 0.47			CP'_A = 0.0	
Validation											
	5	38.4	1.075	1.297	-20.7	0.49	0.38	22.5	0.02	0.01	50.0
	6	43.5	1.556	1.887	-21.3	0.41	0.36	12.2	0.01	0.01	0.0
	7	33.9	0.798	1.089	-36.5	0.38	0.40	-5.3	0.01	0.01	0.0
	8	42.5	1.309	1.415	-8.1	0.45	0.37	17.8	0.01	0.01	0.0
	9	32.2	1.040	1.052	-1.2	2.37	1.80	24.1	0.09	0.10	-11.1
	10	38.4	1.290	1.379	-6.9	1.78	1.71	3.9	0.10	0.09	10.0
				CP'_A = 0.76			CP'_A = 0.09			CP'_A = 0.03	
Both Calibration and Validation											
				CP'_A = 0.47			CP'_A = 0.09			CP'_A = 0.03	

Obs. = Observed; Sim. = Simulated.

Table 4 presents the outputs of model calibration for sediment, soluble nitrogen and soluble phosphorous. The CP'_A for sediment yield calibration was calculated as 0.44. The model output for the soluble nitrogen was always higher than the observed soluble nitrogen concentration, except in event 4, with a CP'_A of 0.47.

The calibrated model was used in the validation process with a new data set of six rainfall events (Table 2). The model validation process required modifation of the input data files to accommodate variability in fertilizer application and land use changes only in the few cells represented by cassava, rubber and orchards.

Table 4 compares the observed data and the model outputs for the pollution parameters, sediment, soluble nitrogen and soluble phosphorous for the validation period. The model over-predicted the sediment yields less than 25%, well within the acceptable limit in

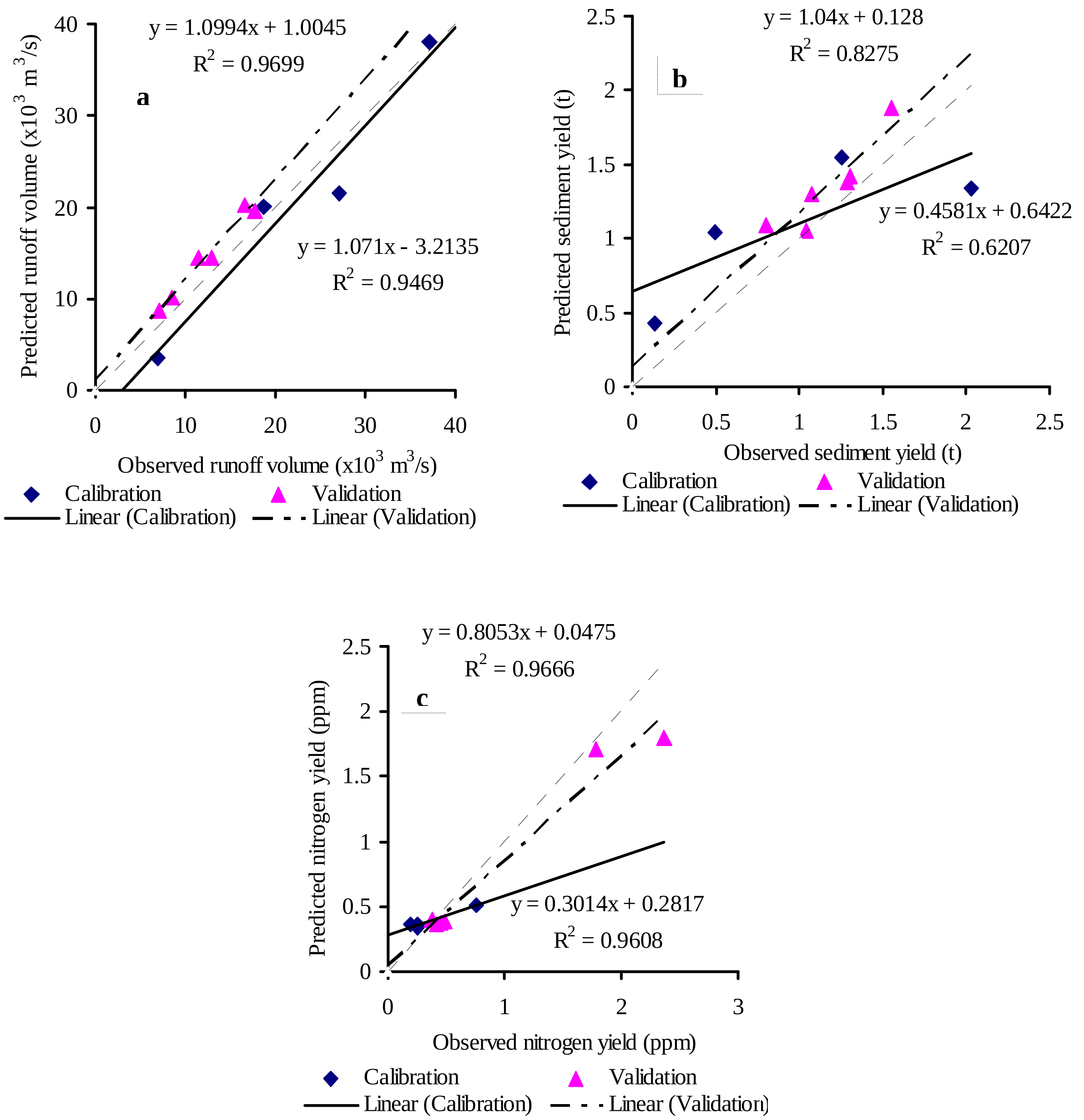

Fig 2. Observed and model predicted outputs.

watershed modeling, where the variability of input parameters is quite large. The sediment yields generated by the validation process gave a CP'_A of 0.76, which is larger than the CP'_A (0.44) for the calibration process (Table 4). When all ten rainfall events are considered, the CP'_A for the sediment yield is 0.47. These results prove that the AGNPS model is capable of simulating sediment yield for the study watershed, however, with lower accuracy than the runoff volume.

The soluble nitrogen yields generated by the validation process shown in Table 4 give CP'_A as 0.09, which is much smaller than the CP'_A from the calibration process (0.47). When all the events are considered, the CP'_A for soluble nitrogen is 0.09, which is satisfactory. The soluble phosphorous concentrations observed and simulated are too low, since seven of ten events analyzed coincide in one point (Table 4). Therefore, it is difficult to make a meaningful analysis of phosphorous data.

Discussion

The percent error of runoff volume for the rainfall events considered varies from as low as 2.7% to 47.8%. The high relative error of runoff volume for rainfall event 4, which occurred on 13 October 1998, may be due to improper representation of the AMC, as there is a gap of about one month between the last two events.

Figure 2a compares the observed and predicted runoff volumes for the calibration and validation. The coefficients of determination (R^2) for calibration and validation are 0.95 and 0.97 respectively. The fact that the fitted regression lines fall near to a 1:1 line show that there is a strong linear relationship and the model performed well with respect to runoff volume.

It has been reported in the literature that AGNPS over-predicts the peak flow[4], in some cases by a factor of three[24]. AGNPS employs the CREAMS equation to predict peak flow. Bonta and Rao[25] applied CREAMS to a watershed in Ohio and found that CREAMS slightly over-predicted peak flow. However, the present study shows the runoff volume calculated by the model is within the acceptable limits. The inability to predict peak flow accurately is a major limitation of the AGNPS model, even in an agricultural watershed. This may be due to the empirical nature of the peak flow relationship, which was developed using data solely from the United States. Furthermore, the study watershed is not an agricultural watershed but has different types of forests, which behave in a different manner than the land use conditions used to develop CREAMS. Therefore, there is a need to consider a different, more suitable approach to determine peak flow that can be applicable to different hydrologic conditions. Alternatively, there could be an option in the AGNPS model where users can change the exponents and parameters of the equations and calibrate the peak flow part of the model.

For the mixed forested watershed used in this study, the observed peak flows are very low compared to the simulated peak flows. This could be because of the dense vegetation, which acts as a barrier for quick runoff, in contrast to the less dense vegetation of an agricultural watershed. Further, the mangrove forests on the downstream end of the watershed and the neglected paddy fields with dense grass cover act as a temporary storage of water, which is released to the streams slowly for longer time duration. Therefore, the dense forest and orchard cover together with the mangrove act as a barrier to quick runoff, decreasing the peak runoff and preventing floods in the downstream.

The model under-predicted the sediment for the first rainfall event and over-predicted for the following rainfall events. This shows clearly that AGNPS may be better suited for agricultural watersheds, which generate more sediment than do mixed forested watersheds. The first rainfall event was during the peak land preparation period for cassava and also the peak of the rainy season. Because of this, the streams are running full with high flow velocities and high sediment loads. Towards the end of the rainy season, the flow velocities and depth of flow in the streams decreases so that most of the sediment flowing is deposited in the pools in the streams and on the mangroves, which could be the reasons for the under-prediction errors such as 111% and 200% for the events 4 and 5 of 1998. In 1999, the rainy season continued beyond October, and that could be a reason why it did not yield results similar to 1998.

The linear relationships shown in Figure 2b between the simulated and observed sediment yields for calibration and validation indicate that sediment yields are generally over-predicted. As the study watershed is a mixed forested watershed, the approach used in AGNPS seems to be not acceptable in simulating sediment yield. Sediment yields predicted by the model were always higher than that of the observed values, which suggests that the mixed forested watershed studied is quite different from an agricultural watershed. This could be because of the effect of mangroves and pools along the canal system, which trap sediments. Further, USLE used in AGNPS is developed for quite different conditions than that of study watershed.

The calibration and validation results show that the model simulated the soluble nitrogen yields within around 25% error, except in event 1. The months June, July and October are the months where fertilizer applications were practiced for cassava and rubber crops. Events 4, 8 and 9 are in the peak fertilization period for rubber and events 5 and 6 for cassava. The higher observed soluble nitrogen amounts in the runoff are due to the coincidence of broadcasting of fertilizer and heavy rains. The other three calibration events, which are toward the end of the rainy season in 1998, result in lower soluble nitrogen contents in runoff as simulated by the model. This could be mainly due to the mangroves acting as natural wetlands reducing nutrient flows from watersheds.

The model outputs are too low to make a meaningful observation with respect to soluble phosphorous prediction. However, the model performance in predicting soluble nitrogen from the study watershed is well within the accepted range. Soluble nitrogen predicted by the model compared favorably, showing a nearly one to one correlation with the observed data. As shown in Figures 2c the model results are scattered about the linear regression line, with slope 0.81 and R^2 0.97 for validation of nitrogen.

Conclusions

The AGNPS model results presented and discussed in this paper are based on two years of data from a mixed forested watershed in Southeastern Thailand. The observed runoff volume shows a linear relationship with the rainfall depth. The model has simulated the runoff volume with good accuracy as reflected by the small values of the coefficient of performance (CP'_A). This indicates that AGNPS is capable for runoff volume prediction for a mixed forested watershed under local conditions.

The peak flow is over-predicted by AGNPS, which shows that the CREAMS equation employed in AGNPS to calculate peak flow may not be suitable for a watershed with mixed forests, especially mangrove forests that can act as a temporary storage of runoff. Sediment yield could be predicted by AGNPS for a mixed forested watershed with moderate accuracy, whereas the soluble nitrogen yields are simulated with relatively high accuracy. Observed and predicted runoff and soluble nitrogen yields show a 1:1 relationship for the study watershed.

The study therefore has revealed that the AGNPS model can be used in simulating runoff volume, sediment and soluble nitrogen yields from a mixed forested watershed, even though the model is primarily developed for agricultural watersheds. The over prediction of sediment by the model could be because of the effect of mangroves, which act as sediment traps.

Acknowledgements

The authors gratefully acknowledge the support and cooperation received from Mrs. Rathana Jindapol and Mrs. Kithima Sivaarthitkul of the Land Development Department of the Royal Thai Government in the fieldwork and in providing all necessary data and information for the study. The authors would also like to thank the Government of Japan for providing a scholarship to the first author of the paper for a Master of Engineering degree at Asian Institute of Technology (AIT), Bangkok, Thailand.

References

1. Sukviboon S, Paladsongkram S, Sumrit D, and Fukada M (1999) Soil erosion and appropriate techniques for improving Map Bon soil with artificial removal of topsoil in LWCC, *The 2nd International Conference on Soil Degradation*, January 25-29, 1999. Khon Kaen, Thailand.
2. Young RA Onstad CA, and Bosch DD (1995) AGNPS: An agricultural non-point source model, In Singh VP (ed.), *Computer Models of Watershed Hydrology*, Water resources publications, Highlands Ranch, Colorado. pp 1001-20
3. Wirojanagud P, Udomchai AW, and Apichatvullop A (1991) *Hydrologic Model of Small Watershed Filling with Weirs and Paddy Land*, Faculty of Engineering, Khon Kaen University, Thailand (In Thai).
4. Mostaghimi S, Park SW, Cooke RA, and Wang SY (1997) Assessment of management alternatives on a small agricultural watershed *Water Res.* **31**(8), 1867-78.
5. Watanasak M (1979) A preliminary study on the evaluation of soil erosion status using universal soil loss equation and LANDSAT imagery techniques in Chonburi and Rayong provinces in Thailand. *Annual Research Abstracts 1979*, Mahidol University, Bangkok, Thailand.
6. Wischmeier WH, Jonhson CB, and Cross BV (1971) A soil erodibility nomograph for farmland and construction sties. *J. Soil and Water Conserv.* **26**(5), 189 – 92.
7. Funnpheng P, Patinavin S, Mekpaiboonwatana S, Pramojanee P, and Eiumnoh A (1991) Application of remote sensing and geographic information system for appraising soil erosion hazard. *International Workshop on Conservation and Sustainable Development*, Asian Institute of Technology, Thailand. pp. 79 – 91.
8. Bingner RL, Mutchler CK, and Murphree CE (1992) Predictive capabilities of erosion models for different storm sizes. *Trans of the ASAE* **35**(2), 505-13.
9. Macalpine ND, Ahmed SM, Young R, Arnold AJ, Sosiak AJ, and Trew DO (1995) Validation of non-point source pollution models for a northern great plains lake. In: *The Proceedings of the International Symposium on Water Quality Modeling*, (Edited by Heatwole C), 539 pp., ASAE, Orlando, Florida.
10. Fisher P, Abrahart RJ, and Herbinger W (1997) The sensitivity of two distributed non-point source pollution models to the spatial arrangement of the landscape. *Hydrol. Proc.* **11**(3), 241-52.
11. Perrone J, and Madramootoo CA (1999) Sediment yield prediction using AGNPS. *J. Soil and Water Conserv.* **54**(1), 415-9.
12. Young RA, Onstad CA, Bosch DD, and Anderson WP (1994) *Agricultural Non-point Source Pollution Model*, *Version 4.3, AGNPS user's guide*, USDA. Morris, MN.
13. Rimchala P, Butsayamanon K, and Chareonpong S (1983) *Land suitability in Chanthaburi*, *Volume 350, Soil survey report*. Kung Krabaen Bay Royal Development Study Centre, Thamai district, Chanthaburi province, Soil Survey Division, Land Development Department, Bangkok. Thailand (In Thai).

14. Klute A (1986) *Methods of Soil Analysis, Part I, Physical and Mineralogical Methods*. American Society of Agricultural Engineers, Soil science society of America. Madison. Wisconsin.
15. Page AL (1986) *Methods of Soil Analysis, Part II, Chemical and Microbiological Properties*. American Society of Agricultural Engineers, Soil Science Society of America. Madison, Wisconsin.
16. Greenberg AE, Connors JJ, and Jenkins D (1986) *Standard Methods for the Examination of Water and Wastewater.* American Public Health Association, Washington D.C.
17. Lal R (1988) *Soil Erosion Research Methods*. Soil and Water Conservation Society, Ankeny, Iowa.
18. Chow VT, Maidment DR, and Mays LW (1988) *Applied Hydrology*. McGraw-Hill Book Company, Singapore.
19. Najim MMM (2000) *Assessment of the AGNPS Model in a Tropical Watershed, Chanthaburi, Thailand.* M.Eng. Thesis, Asian Institute of Technology, Bangkok, Thailand.
20. Schwab GO, Fangmeier DD, Elliot WJ, and Frevert RK (1993) *Soil and Water Conservation Engineering*. John Wiley and Sons Inc., New York, USA.
21. Smedema LK, and Rycroft DW (1983) *Land Drainage*. Batsford, London.
22. Morgan RPC (1996) *Soil Erosion and Conservation*. Longman Group UK Ltd.
23. James LD, and Burgess SJ (1982) Selection, calibration and testing of hydrologic models In Haan CT, Johnson HP, and Brakensiek DL (eds), *Hydrologic Modeling of Small Watersheds*. American Society of Agricultural Engineers, Michigan.
24. Rode M, and Frede HG (1997) Modification of AGNPS for agricultural land and climate conditions in central Germany. *J. Environ. Qual*. **26**(1), 165-72.
25. Bonta JV, and Rao AR (1992) Estimating peak flows from small agricultural watersheds. *J. Irri. and Drain. Eng.* **118**(1), 122-37.